PSI-SAW and PSI-MARCOS Hybrid MCDM Methods

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ABSTRACT

This paper presents a study on the hybridization of Multi-Criteria Decision-Making (MCDM) methods: Preference Selection Index (PSI), Simple Additive Weighting (SAW), and Measurement Alternatives and Ranking according to COmpromise Solution (MARCOS). The hybridization was conducted between the PSI and the other two methods, resulting in new methods, namely PSI-SAW and PSI-MARCOS. For each specific problem, applying these two hybrid methods to rank alternatives among the available options produces three different sets of rankings: one created by PSI, one by the hybrid PSI-SAW, and one by the hybrid PSI-MARCOS. The accuracy of the proposed models was tested in three different cases. The test results show that both proposed models exhibit high accuracy. This study provides users with highly accurate and useful methods for MCDM.

Keywords-MCDM; hybrid model; PSI-SAW; PSI-MARCOS

I. INTRODUCTION

In life and work, making the decision to choose one solution among many available options is extremely important, especially when multiple criteria need to be considered simultaneously. When faced with complex choices, each solution often has its own advantages and disadvantages, affecting various factors such as cost, time, efficiency, and risk. Making the right choice helps to optimize results, save resources, and achieve goals more effectively. MCDM methods have been widely used to support this decision-making process [1, 2]. These methods help to systematize and analyze different criteria, enabling more objective and accurate decisions. Using MCDM not only makes the decision-making process transparent and scientifically grounded but also helps decision-makers feel more confident in their choices, knowing that all important factors have been carefully considered [3, 4].

The rapid development of MCDM methods has resulted in an impressive figure of more than 200 different methods [5]. However, this also complicates the choice of which method to use, as the rankings of alternatives can vary significantly when using different methods [6]. One of the main reasons for this phenomenon is the different ways of weighing the criteria used by various methods [7-9]. Many studies have shown that using a method to rank alternatives without the need to calculate weights for the criteria can make the rankings less variable [10]. However, this approach loses the importance of distinctions between criteria [11]. This situation presents a challenge to whether to use MCDM methods that require weighting criteria or those that do not. The use of hybrids between these two types of methods is expected to address this challenge.

PSI is an MCDM method in which users do not need to use methods to calculate weights for the criteria because it inherently calculates these weights. With the advantage of not requiring weight calculation methods, PSI has attracted significant attention in various fields, such as selecting 3D printers [12], scholarship recipient selection [13], personnel selection, robot selection, machining method selection, air quality assessment in offices [14], cutting process and cutting fluid selection [15], and ranking transportation companies [16]. However, all studies that have applied the PSI method have only used it as an MCDM method without exploiting its second function of calculating criteria weights. This study utilizes this function. This means that the criteria weights calculated by PSI will be used to rank alternatives using other MCDM methods, resulting in hybrids between PSI and other MCDM methods. This study selected SAW and MARCOS to hybridize with PSI. SAW was chosen because it is known as a simple method and is considered a basis for developing other MCDM methods [17]. MARCOS was chosen for its many advantages, such as very stable alternative rankings [18], the best alternative being independent of the number of alternatives and less dependent on the weighting method used [19], and the ability to combine with various data normalization methods [20].

The hybrids between PSI, SAW, and MARCOS are two new methods: PSI-SAW and PSI-MARCOS. Applying these hybrid models to solve specific problems results in three alternative rankings: one from applying PSI and the other two from applying PSI-SAW and PSI-MARCOS. The notable advantage of this hybrid approach compared to all existing methods is that it creates three sets of rankings for the options for each problem, using only the PSI, SAW, and MARCOS methods without needing any additional weighting methods. For each specific problem, making the final decision based on the three sets of rankings obtained through this approach is considered the first discovery of this research.

II. LITERATURE REVIEW

Due to the large number of MCDM methods available, deciding which method to use becomes a complex decision [5]. Many studies have indicated that when different MCDM methods are used to rank alternatives, the rankings often differ, and sometimes even contradict each other [6]. Due to this, for each specific problem, it is common not to rely on a single MCDM method but rather to employ several methods simultaneously [16], or to use a technique that takes advantage of the strengths and mitigates the weaknesses of multiple methods at the same time [21, 22]. In practice, combining methods has proven to be a trend to meet these challenges [23]. For instance, in [24], five methods, namely Multi-Attributive Border Approximation area Comparison (MABAC), Combined Compromise Solution (COCOSO), Multi Atributive Ideal-Real Comparative Analysis (MAIRCA), Vlsekriterijumska optimizacijaI KOmpromisno Resenje (VIKOR), and Range Of Value (ROV), were combined to rank solutions in metal milling processes and assess air quality in office environments. Delphi and the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) have been combined to rank layout alternatives in manufacturing workshops [25]. The SAW and Delphi methods have also been combined to rank online learning platforms during the Covid-19 pandemic [22]. Stepwise Weight Assessment Ratio Analysis (SWARA) and Complex Proportional Assessment (COPRAS) have been merged to select the best software for bank management [26]. Delphi and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) have been combined to select public relations personnel for Taiwan's tourism industry [27]. VIKOR, TOPSIS, and Elimination and Choice Expressing Reality (ELECTRE) methods have been fused to evaluate the efficiency of bus station operations [28]. In [29], the Multi-Objective Optimization by Ratio Analysis (MOORA) and COPRAS methods were amalgamated to rank metal polishing solutions.

Combining MCDM methods to rank alternatives has been applied in various fields. However, in previously published studies, the methods involved in the combination process required additional methods to calculate criteria weights. This is a significant challenge for decision-makers, as research has shown that the choice of weight calculation method greatly influences the ranking of alternatives [7-9]. This underscores the necessity of combining MCDM methods without needing additional methods for criteria weighting. PSI serves as an MCDM method for ranking alternatives, where criteria weights are automatically determined. However, this feature of the PSI method has not been fully utilized in published studies. Combining PSI with another MCDM method would help decision-makers avoid the dilemma of selecting a weight calculation method while ensuring that the rankings of alternatives are not unduly affected by the chosen weight calculation method. Given the advantages of the SAW and MARCOS methods, this study selected them to combine with the PSI method.

III. HYBRID MODELS OF PSI WITH SAW AND MARCOS

To hybridize PSI with the SAW and MARCOS methods, the sequence of applying these methods needs to be clarified. Assume there are *m* alternatives to be ranked and *n* criteria for each alternative. Criteria that are maximized are denoted as type B, while criteria that are minimized are denoted as type C. The value of criterion *j* for alternative *i* is denoted as x_{ij}, with $i = 1, \ldots, m$, and $j = 1, \ldots, n$. Then, a decision matrix is formed as shown in (1).

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \ddots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

The PSI method is applied in the following sequence [30]:

- Normalize the data according to (2) and (3):

$$n_{ij} = \frac{x_{ij}}{max(x_{ij})} \quad ij \quad j \in B \quad (2)$$

$$n_{ij} = \frac{min(x_{ij})}{x_{ij}} \quad ij \quad j \in C \quad (3)$$

- Calculate the average normalized value according to (4):

$$n = \frac{\sum_{i=1}^{m} n_{ij}}{m} \quad (4)$$

- Calculate the preference value for each criterion according to (5):

$$\varphi_j = \sum_{i=1}^{m} \left(n_{ij} - n\right)^2 \quad (5)$$

- Calculate the weight for each criterion according to (6):

$$w_j = \frac{1-\varphi_j}{\sum_{j=1}^{n}(1-\varphi_j)} \quad (6)$$

- Calculate the score for each alternative according to (7). Rank the alternatives based on the principle that the best alternative is the one with the highest score:

$$\theta_i = \sum_{j=1}^{n} n_{ij} \cdot w_j \quad (7)$$

According to published materials, all studies that applied the PSI method used all these formulas to rank the alternatives. However, the weights of the criteria have been determined after using the first six formulas. The mere use of the first six formulas of the PSI method has not yet received attention from scientists. This can be considered a waste of resources (a waste of a weighting method). This study will use the weights of the criteria calculated by the PSI method to rank the alternatives using the SAW and MARCOS methods, creating the PSI-SAW and PSI-MARCOS hybrids.

The SAW method is applied in the following sequence [31]:

- Normalize the data according to (2) and (3).
- Calculate the score for each alternative according to (8). Rank the alternatives in descending order of their scores:

$$V_i = \sum_{j=1}^{n} w_j \cdot n_{ij} \quad (8)$$

The MARCOS method is applied in the following sequence [18]:

- Determine the ideal alternative *AI* according to (9) and (10):

$$AI_j = \begin{cases} max(x_{ij}) \\ i = 1, 2, \ldots, m \quad if \quad j \in B \\ j = 1, 2, \ldots, n \end{cases} \quad (9)$$

$$AI_j = \begin{cases} min(x_{ij}) \\ i = 1, 2, \ldots, m \quad if \quad j \in C \\ j = 1, 2, \ldots, n \end{cases} \quad (10)$$

- Determine the anti-ideal alternative *AAI* according to:

$$AAI_j = \begin{cases} min(x_{ij}) \\ i = 1, 2, \ldots, m \quad if \quad j \in B \\ j = 1, 2, \ldots, n \end{cases} \quad (11)$$

$$AAI_j = \begin{cases} max(x_{ij}) \\ i = 1, 2, \ldots, m \quad if \quad j \in C \\ j = 1, 2, \ldots, n \end{cases} \quad (12)$$

- Normalize the data according to (13) and (14):

$$n_{ij} = \frac{x_{ij}}{AI_j} \quad ij \quad j \in B \quad (13)$$

$$n_{ij} = \frac{AI_j}{x_{ij}} \quad ij \quad j \in C \quad (14)$$

- Calculate the normalized values considering the weights of the criteria according to:

$$c_{ij} = W_j \cdot n_{ij} \quad (15)$$

- Calculate the quantities S_i, S_{AAI}, and S_{AI} according to:

$$S_i = \sum_{j=1}^{n} C_{ij} \quad (16)$$

$$S_{AI} = \sum_{j=1}^{n} AI_j \quad (17)$$

$$S_{AAI} = \sum_{j=1}^{n} AAI_j \quad (18)$$

- Calculate the coefficients K_i^+ and K_i^- according to:

$$K_i^+ = \frac{S_i}{S_{AI}} \quad (19)$$

$$K_i^- = \frac{S_i}{S_{AAI}} \quad (20)$$

- Calculate the quantities $f(K_i^+)$ and $f(K_i^-)$ according to:

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \quad (21)$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \quad (22)$$

- Calculate the score $f(K_i)$ of the alternatives according to (23). Then, rank the alternatives in descending order of their scores.

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}} \quad (23)$$

Based on the steps for applying the PSI, SAW, and MARCOS methods, the hybrid model of these methods is illustrated in Figure 1.

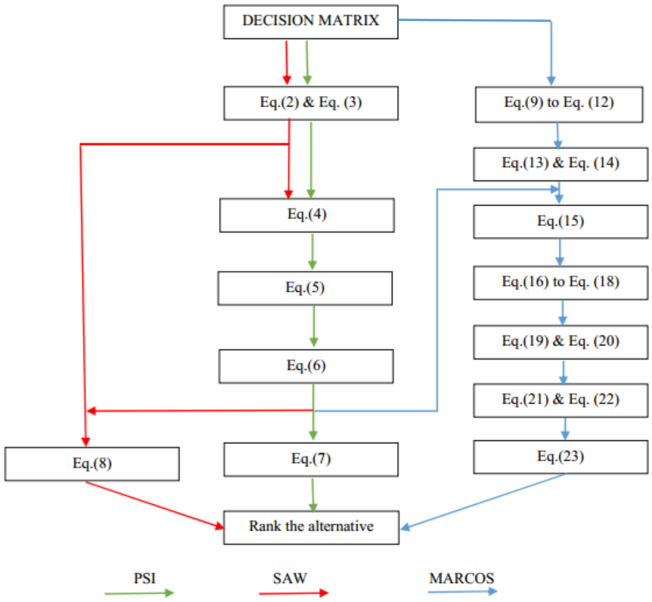

Fig. 1. Hybrid models of MCDM methods.

The hybrid model shown in Figure 1 can be explained as follows: the alternatives are ranked using three different methods, namely PSI, SAW, and MARCOS. In this context, when ranking the alternatives using the SAW and MARCOS methods, the set of criterion weights calculated by the PSI method is used. These two cases are called the PSI-SAW hybrid and the PSI-MARCOS hybrid. Tests were carried out to assess the model's accuracy related to material selection. The reason for choosing material selection is that it is a very complex issue, significantly affecting many aspects, such as product performance, production costs, environmental impacts, etc. [32].

IV. RESULTS AND DISCUSSION

A. *Optimizing Material for Connecting Rod Manufacturing*

Table I summarizes four types of steel commonly used for manufacturing connecting rods: 1080, 18CrMo4, 4130, and S48C [33]. Fifteen parameters were used to describe each type of material for manufacturing the connecting rod: C1 is the maximum stress a material can withstand when being pulled before breaking, C2 is the stress at which the material begins to deform plastically, C3 is the material's ability to elongate before breaking, where lower values are better, C4 is the material's resistance to uniform compression, C5 is the material's resistance to shear deformation, C6 is the ratio of transverse strain to axial strain when the material is subjected to axial stress, C7 is the hardness of the material measured by the Brinell scale, C8 is the hardness of the material measured by the Rockwell scale, C9 is the ease of machining the material to achieve the desired specifications, C10 is the ratio of the stress applied to the material to the strain produced, C11 is the degree to which the material expands when heated, with lower values being better, C12 is the material's ability to conduct heat, C13 is the amount of heat per unit mass required to raise the temperature by 1°C, C14 is the temperature at which the material changes from solid to liquid, and C15 is the mass per unit volume of the material.

The values of C1 to C15 determined by the PSI method are 0.0671, 0.0568, 0.0613, 0.0694, 0.0725, 0.0743, 0.0658, 0.0717, 0.0734, 0.0708, 0.0572, 0.0559, 0.0741, 0.0556, and 0.0744, respectively. These weight values were used to rank the types of steel using the SAW and MARCOS methods. Figure 2 shows the ranking results of the types of steel using the three methods: PSI, SAW, and MARCOS. It is important to note that when ranking the types of steel using the SAW and MARCOS methods, the criterion weights calculated by the PSI method are used, thus referred to as the PSI-SAW hybrid model and the PSI-MARCOS hybrid model.

TABLE I. TYPES OF STEEL FOR CONNECTING RODS

Steel	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
	Mpa	Mpa	%	Gpa	Gpa	-	HB	HRC	%	Gpa	10^{-6}/k	W/m.K	J/kg.K	°C	kg/m^3
1080	440	205	15	140	80	0.29	126	71	70	205	8	52	440	820	7800
18CrMo4	517	365	33	140	80	0.285	137	75	60	210	14	20	440	760	7850
4130	560	460	21.5	140	80	0.285	217	95	70	200	22.3	42.7	420	460	7800
S48C	765	625	16.5	200	65	0.3	186	80	65	275	10	25	460	1480	7700

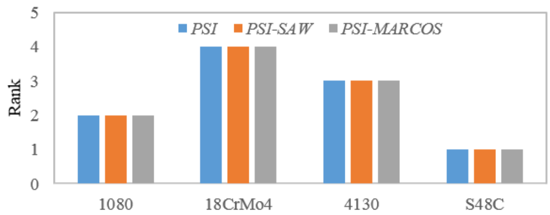

Fig. 2. Ranking of materials for connecting rods.

Figure 2 clearly shows that the ranking of the steel types does not differ when using different methods. Specifically, when using the PSI method and the two hybrid methods PSI-SAW and PSI-MARCOS, the priority ranking for the types of steel is consistently S48C > 1080 > 4130 > 18CrMo4. Thus, all the methods applied confirm that S48C is the best steel for manufacturing connecting rods. In [33], the ranking of these four types of steel was also performed using the PIV method, and the criterion weights were calculated using three methods: equal weights, entropy weights, and MEREC weights. Interestingly, S48C was also identified as the best steel in all surveyed cases. This result indicates that the PSI-SAW and PSI-MARCOS hybrid models provide highly accurate methods. These methods are fully reliable for users to apply in this case.

B. Optimizing Material for Gearbox Housing Manufacturing

Table II summarizes 14 different types of steel commonly used for manufacturing gearbox housings [34]. Each type of steel used for manufacturing the gearbox body is evaluated based on five criteria. C1 is yield strength, indicating the stress at which the steel begins to deform plastically. C2 is tensile strength, representing the maximum stress that steel can withstand when pulled before breaking. C3 is the elongation at the break, reflecting the steel's ability to stretch before breaking. C4 is the area reduction, showing the degree of decrease in the cross-sectional area at the breaking point. Finally, C5 is impact toughness, indicating the steel's ability to withstand impact forces without cracking or breaking. In all five criteria, higher values indicate better quality and durability of steel in mechanical applications.

Formulas from (1) to (6) are used again to calculate the weights for the criteria C1, C2, C3, C4, and C5 using the PSI method, with the results being 0.1402, 0.1869, 0.2082, 0.2728, and 0.1918, respectively. These values for the weights of the criteria are used to rank the types of steel using the SAW and MARCOS methods. In this case, the ranking of steel types for gearbox housing manufacturing is also performed using the PSI method and the two hybrid models PSI-SAW and PSI-MARCOS, with the results shown in Figure 3.

TABLE II. TYPES OF STEEL FOR GEARBOX HOUSINGS

Steel	C1	C2	C3	C4	C5
	kg/mm^2	kg/mm^2	%	%	kgm/cm^2
15Cr	50	70	12	45	7
20Cr	65	80	11	40	6
30Cr	70	90	12	45	7
35Cr	75	93	11	45	7
40Cr	80	100	10	45	6
C30Mn	32	55	20	45	8
C40Mn	36	60	17	45	6
30CrMnTi	130	150	9	50	6
40CrMnTiB	80	100	11	45	8
33CrSi	70	90	13	50	8
40CrSi	110	125	12	40	3.5
30CrMo	75	95	11	45	8
35CrMo	85	98	12	45	8
40CrNi	80	100	11	45	7

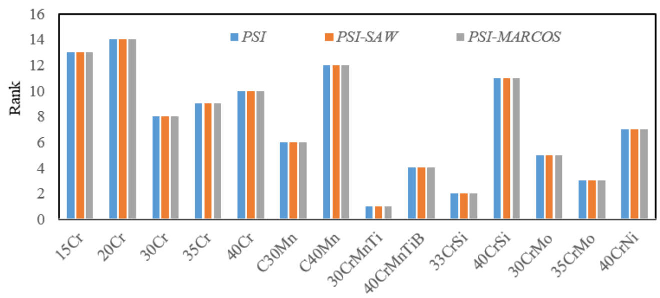

Fig. 3. Ranking of materials for gearbox housings.

In this case, the ranking of the steel types is also entirely consistent when ranked using the PSI method and the two hybrid models PSI-SAW and PSI-MARCOS. Among the 14 steel types surveyed, 30CrMnTi is identified as the best steel for manufacturing gearbox housings. In [34], these 14 steel types were ranked using TOPSIS and RAM, and the weights of the criteria were calculated using equal, entropy, and LOPCOW. Interestingly, all combinations of MCDM methods with weighting methods in this study also identified 30CrMnTi as the best steel. This result once again confirms that PSI-SAW and PSI-MARCOS provide highly accurate methods that are also fully reliable for users to apply in this case.

C. Optimizing Material for Gear Manufacturing

Table III summarizes nine different types of steel commonly used for gear manufacturing [35]. Materials used for manufacturing gears are evaluated based on criteria, including C1, core hardness, where smaller values are better, as lower hardness reduces the risk of fracture during operation. C2 is strength, indicating the material's ability to withstand stress without failing. C3 is fatigue strength, reflecting the material's ability to endure repeated stress without fatigue or cracking. C4 is bending strength, showing the material's ability to withstand bending forces without breaking. Finally, C5 is the tensile strength, representing the maximum stress that the material can withstand when pulled before breaking. The four criteria from C2 to C5 are the larger, the better, as higher values indicate better quality and durability of the material for gears in mechanical applications. Once again, the weights of the five criteria C1, C2, C3, C4, and C5 are calculated using the PSI method, with the corresponding values of 0.3466, 0.1295, 0.1566, 0.1733, and 0.1939, respectively. Figure 4 shows the ranking of steel types when ranked using PSI, PSI-SAW, and PSI-MARCOS.

TABLE III. TYPES OF STEEL FOR GEAR MANUFACTURING

Alt.	C1	C2	C3	C4	C5
A1	200	200	330	100	380
A2	220	220	460	360	880
A3	240	240	550	340	845
A4	270	270	630	435	590
A5	270	270	670	540	1190
A6	240	585	1160	680	1580
A7	315	700	1500	920	2300
A8	315	750	1250	760	1250
A9	185	500	430	430	625

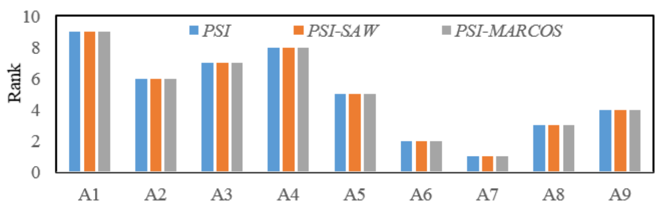

Fig. 4. Ranking of materials for gear manufacturing.

Again, in this case, the ranking of steel types is entirely consistent when ranked using the PSI method and the two hybrid models PSI-SAW and PSI-MARCOS. Thus, A7 is identified as the best option. A7 was also determined as the best option when ranking the nine options using the Collaborative Unbiased Rank List Integration (CURLI), Evaluation Based on Distance from Average Solution (EDAS), TOPSIS, and PROMETHEE methods [35]. All of these findings confirm once again that the PSI-SAW and PSI-MARCOS hybrids achieved very high accuracy. These methods are fully reliable for users to apply in this case.

In all three cases examined, the rankings of the options are consistently aligned when using the three methods, PSI, PSI-SAW, and PSI-MARCOS. Additionally, the best option identified in each case is also consistently aligned among these three methods and consistent with other MCDM methods. All of these affirm unequivocally that the integration of PSI-SAW and PSI-MARCOS is a scientifically sound approach, yielding useful tools for users in material selection.

V. CONCLUSION

This study presented two new MCDM methods, PSI-SAW and PSI-MARCOS, by combining PSI with SAW and MARCOS. The effectiveness of these methods was tested through three different cases in material selection, showing that the ranking of materials remained the same when using each method. In particular, the best material identified was consistently the same when using these three and other MCDM methods. The discovery that using only the hybridization of the three methods PSI, SAW, and MARCOS, without needing any additional methods to calculate the weights for the criteria, yet still being able to produce three sets of ranking results for the options where the best option is consistently found across all three sets of data is a significant breakthrough. This creates a strong confidence for users in the final decision.

This excellent result may be due to the simplicity of the PSI and SAW algorithms, which helps minimize the ranking bias of the alternatives. Additionally, leveraging the advantages of the MARCOS method, such as stable ranking results and independence from the number of alternatives or the weighting determination method, also contributed to the success of the proposed methods. This study has introduced new and unique approaches to develop highly accurate MCDM methods. Future studies should evaluate the effectiveness of the proposed methods in other fields. Additionally, creating hybrids between PSI and other MCDM methods is also encouraged for future implementation. However, this study has not considered the case where the decision matrix contains zero values. If this occurs, data normalization in both PSI and SAW methods cannot be performed. Finding a solution to overcome this limitation to create a hybrid model that can be applied in all cases is also a research direction that needs to be pursued in the future.

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